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Frigaard, Peter Bak; Pedersen, Jan

*Publication date:*  
2002

*Document Version*  
Early version, also known as pre-print

[Link to publication from Aalborg University](#)

*Citation for published version (APA):*

Frigaard, P. B., & Pedersen, J. (2002). *Scour Protection of Off-Shore Windmills*. Abstract from The 28th International Conference on Coastal Engineering (ICCE 2002), Cardiff, Wales, United Kingdom.

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## Scour Protection of Off-shore Windmills.

Peter Frigaard<sup>1</sup> & Jan Pedersen<sup>2</sup>,

<sup>1</sup> Hydraulics & Coastal Engineering Laboratory, Aalborg University, Sohngaardsholmsvej 57, DK-9000 Aalborg, Denmark,  
email Peter.Frigaard@civil.auc.dk, fax +45 9814 2555, tel +45 9815 8479

<sup>2</sup> Techwise A/S, Kraftværksvej 53, DK-7000 Fredericia, Denmark  
email Jpe@techwise.dk, tel +45 7923 3266

### 1. INTRODUCTION

In the Eighties and Nineties wind turbines with a total rated power of app 1000 Mega watt were erected in Denmark. Today more than 13% of the electrical consumption in Denmark is covered by electricity from wind turbines. Though, due to lack of good positions for the windmills and due to growing opposition against the wind turbines, the Danish government initiated in 1999 the construction of several large off-shore wind farms. In total, installation of 4000 Mega watt rated power were planned off-shore. From this, 750 Mega watt rated power shall be constructed before 2008.

In May 2001 the worlds largest off-shore wind farm so far, the Middelgrunds Project was opened. The Middelgrunds Project consist of 20 wind turbines at 2 Mega watt each.

In the coming period 2001-2003 two major off-shore wind farms, Horns Rev east of Esbjerg and Rødsand south of Lolland will be constructed on 6-13 meters of water depth. Each of the farms will be app. 150 Mega Watt.

The two wind farms will be situated in areas with significant wave heigths up to 5 meters, currents of app. 1 m/sec.

Several tecnical aspects during design of the wind parks were undertaken by the contractors consultants SEAS and TECHWISE. However, focus in

the paper will solely be put on design of the scour protection of the wind turbine foundations. Results from laboratory testings with the scour protections will be described.

### 2. LABORATORY TESTING OF SCOUR

Scour around vertical piles was previously tested by several researchers in steady current, see Breusers (1977) for a review.

Sumer et al. (1992) and Carreiras et al. (2000) investigated scour around vertical piles in waves. Previous research has indicated equilibrium scour hole depths in the interval 1 - 1.5 times the diameter of the pile.

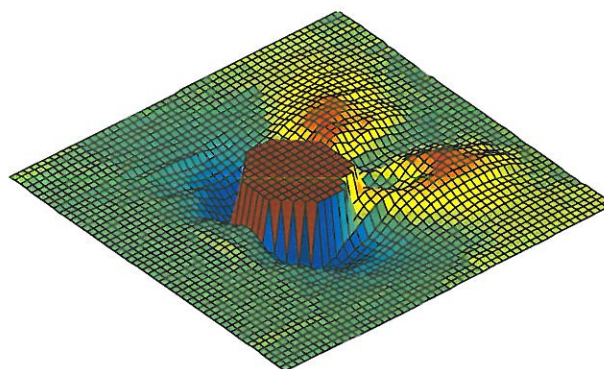


Figure 1: Example of laboratory measured scour around a pile. Waves and current from lower left.

Wind turbine foundations are not necessary vertical piles. Gravity foundations are often used. More-

over, some foundations will include an iceconus.

Recently several laboratory tests have been undertaken in order to evaluate the effect of such irregular geometries on the scour in combined current and waves.

### 3. SCOUR PROTECTION

Scour holes corresponding to the equilibrium state will not be accepted for the wind turbines. Therefore a proper scour protection has to be designed.

Generally small scale model testing with scour protection will introduce scale effects. Therefore no direct scale testing with the scour protection have been performed. Instead comparative testings and indirect testings had to give the design of the scour protection.

Considerations about these scale effects and thoughts leading to the final design will be described in the paper.

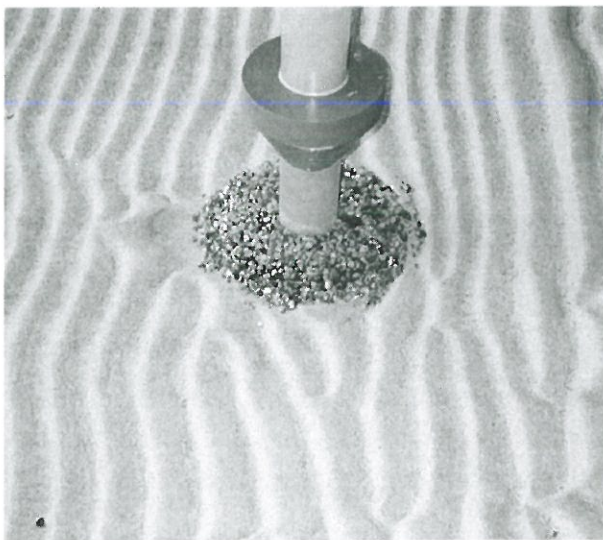


Figure 2: Example of laboratory test with scour protection on a live bed.

The paper will focus on the scour design of the wind turbine foundations in the Horns Rev project. Presently Teshwise already has recieved public bids on the foundation works, but no decision on final design has been taken yet.

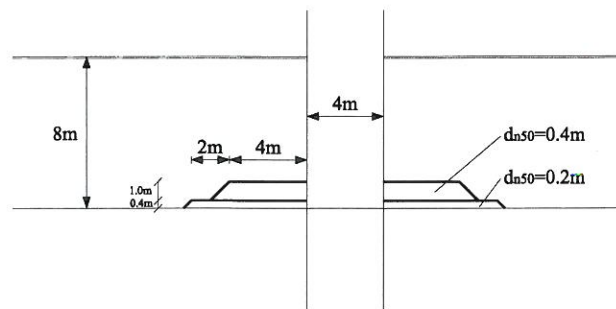


Figure 3: Example of scour protection around pile. The showed scour protection is constructed of quarry rock.

### 4. FIELD OBSERVATIONS

Construction of the two large wind farms at Horns Rev and Rødsand will start autumn 2001. Behaviour of the scour protection will be monitored during the coming years. Unfortunately no measurements can be expected before 2003.

Instead, three years of experience from a monitored testpile placed at Horns Rev and experience from scour protection of the Middelgrunds Project will be discussed.

### 5. REFERENCES

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